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The Triassic Aghdarband Group: Volcanism and Geological Evolution

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With 6 Figures

NE-Iran
Aghdarband
Triassic
Volcanism
Paleogeography
Geodynamics

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Zusammenfassung

Ähnlich wie Band-i-Turkestan, der nördliche Hindukusch und der nördliche Pamir, wurde auch das Gebiet des heutigen Kopet Dagh während des jüngeren Paläozoikums an die Turan-Platte angegliedert. Während des Perm wurden Teile dieser angegliederten Gebiete gehoben, erodiert und – vor allem deren südliche Teile – von roten kontinentalen Ablagerungen bedeckt. Der aktive Rand der Paläotethys wanderte gegen Süden und ein neuer vulkanisch-plutonischer Bogen entstand südlich des Herzynischen Orogens, unmittelbar nördlich der neuen Subduktionszone der Paläotethys. Während der Triaszeit ist ein bogenförmiger vulkanisch-sedimentärer Gürtel verfolgbar, vom südlichen Kaukasus über den Kopet Dagh bis zum nördlichen Pamir. Ein kimmerisch deformierter Abschnitt dieses Rand- („back arc"-)Beckens tritt in dem Erosionsfenster von Aghdarband zutage. Die triadische Aghdarband-Gruppe ist hier in 4 lithologische Formationen unterteilt, von denen die 3 älteren eine sedimentäre Schichtfolge von einer Seichtwasser-Karbonat-Plattform (höhere Untertrias) zu Tiefsee-Ablagerungen andesitischer und trachytischer Vulkanoklasten (mittlere Trias bis tiefste Obertrias) repräsentieren. Nach einer Schichtlücke folgt darüber eine zweite Seichtwasser-Schichtfolge (mittleres bis oberes Nor) mit einem Kohlenflöz an ihrer Basis.

Eine Analyse dieser beiden Sedimentationszyklen wird unter Hinweis auf die geologischen Ereignisse („events") während der Trias-Zeit vorgestellt.

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Abstract

During the late Paleozoic, the area of the Kopet Dagh had been accreted to the Turan plate as were the Band-i-Turkestan, the N Hindu Kush and the N Pamir. During Permian time, parts of these accreted terranes were uplifted, eroded and mainly this southern areas covered by red continental deposits. The Paleotethys active margin migrated to the S and a new volcano-plutonic arc was emplaced S of the Hercynian collage, just to the N of the new Paleotethys subduction zone. During Triassic time, an arcuate marine volcano-sedimentary belt is traceable from the S Caucasus through the Kopet Dagh to the N Pamir. A Cimmerian deformed segment of this back arc basin is now outcropping in the erosional window of Aghdarband. Lithologically, the Triassic Aghdarband Group is subdivided into 4 formations; it shows a first sedimentary sequence from shallow water carbonate platform (latest early Triassic) through deep water andesitic to trachytic volcaniclastics (middle to earliest late Triassic). After a main break in the sedimentation, the first sequence is followed by a second transgressive sequence (middle to late Norian) of a shallow clastic ramp with a coal seam at the base.

An analysis of these two sedimentary cycles with the Triassic events is presented.

1. Introduction

During late summer 1972, one of us (A. B.) had the opportunity to study the Aghdarband area with Professors BRÖNNIMANN and ZANINETTI (University of Geneva) and Dr. BOZORNIA (Tehran). We sampled two lithological sections, one in the vicinity of the Sina coal Mine (E of the Aghdarband village [Stratigraphic sections 1–9 on the geological map in A. RUTTNER, Pl. 1 in this vol.]) and the other in the Sefid Kuh area (W of Aghdarband). Composed samples Br 3049 to 3137 have been deposited at the Geological Department of the NIOC in Tehran and the thin sections from the Sina area samples have been studied by the authors. Additionally, we received in 1981 and in 1982 from Dr. RUTTNER complementary Triassic samples and thin sections. With one of the authors (A. B.), R. CAS and H. SARP have contributed to the analysis of the volcaniclastic facies of these new samples.

Lithologically, the Triassic rocks of the erosional window of Aghdarband, called by RUTTNER (1984) the Aghdarband Formation, but renamed in this volume to become the Aghdarband Group, are subdivided in four formations named respectively Sefid Kuh, Nazarkardeh, Sina and Miankuhi from the older to the younger. These Triassic Formations are bounded to the south by folded and thrusted (?)Paleozoic epimetamorphic rocks (southern Frame) and to the north mainly by late Devonian and early Carboniferous slightly metamorphosed rocks (northern Frame). In the following chapters, we shall refer to these subdivisions and to the general stratigraphic section (RUTTNER, this vol., Fig. 4) and our Fig. 6.

2. Structural Units

Structurally, from field studies, geological sketch map, cross sections analysis and from the geological map (Pl. 1 in A. RUTTNER, this vol.), three tectonic slices composed mainly of Triassic rocks can be recorded from the central part of the Aghdarband erosional window (Fig. 1).

The northern one (Slice I) is bounded by 2 vertical faults and contains a tectonically reduced stratigraphic column. The Sefid Kuh Formation appears only to the NW of the Aghdarband village and is in tectonic contact with the "marble" (early Carboniferous) of the northern Frame. The Sandstone Member of the Sina

Fig. 1.
Sketch map of the Aghdarband area with the position of the Triassic tectonic Slices I to III.
After A.W. RUTTNER (this volume).
K-e-N = Kuh-e-Nazarkardeh; K-e-P = Kuh-e-Palang.

The Triassic Aghdarband Group

Miankuhi Formation
Sina Volcanic Formation
M3 Shale Member (former "Member 3")
Litharenite
Faqir Marl Bed ("Fossil Horizon 2")
M2 Sandstone Member (former "Member 2")
Nazarkardeh Formation ("Fossil Horizon 1")
Sefid Kuh Limestone Formation
Site of the type section

Fossil localities

37 Ammonoids
56 *Daonella lommeli*
× 61 Radiolarians and spicules (poriferans)

Qara Gheitan Formation (Lower Scythian)

Jurassic and Cretaceous Coverbeds

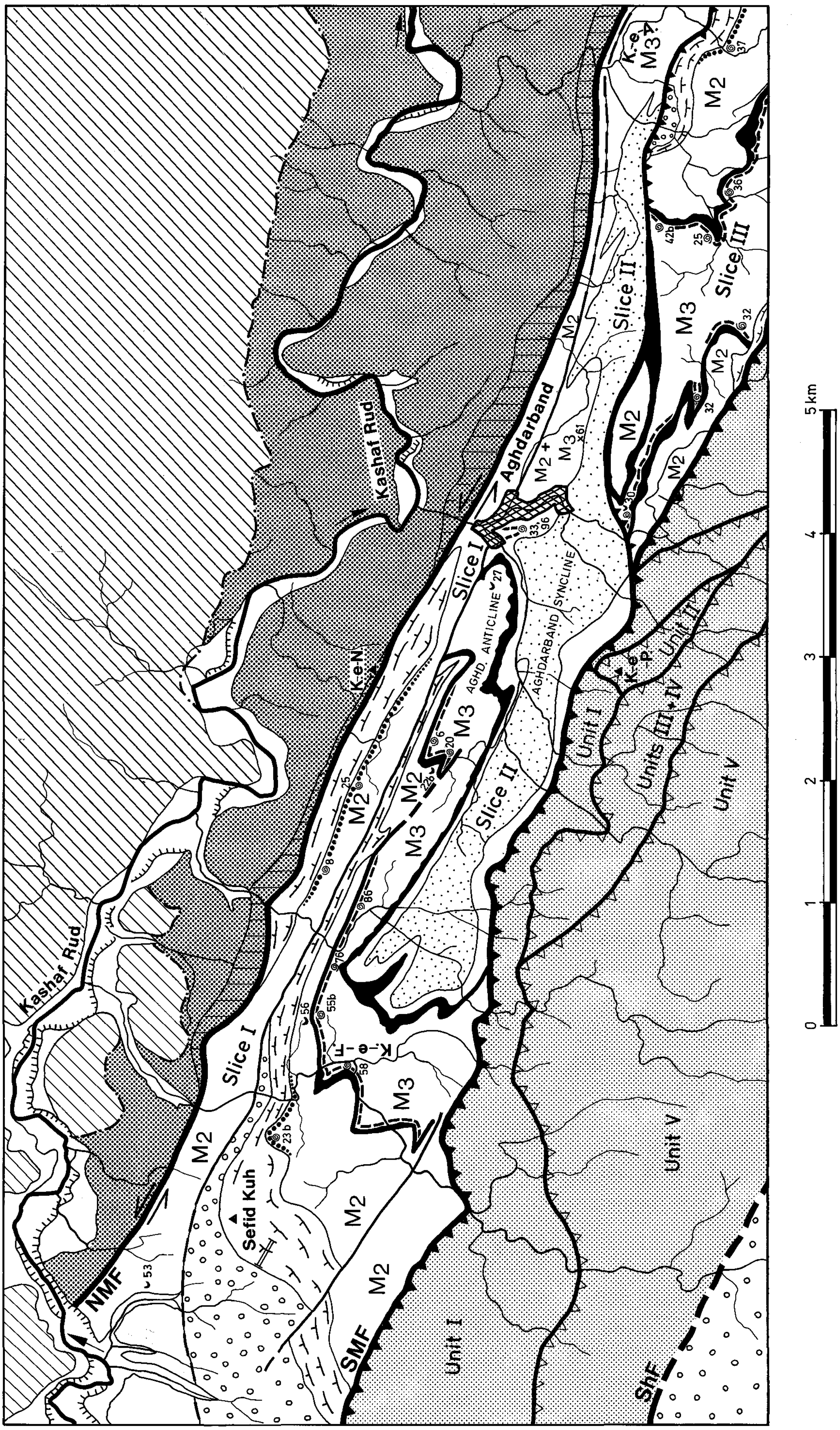
Northern Frame

"Marble" (Lower Carboniferous)
Volcaniclastics, limestone (U. Devonian)

Southern Frame

Units I–V

NMF Northern Main Fault
SMF Southern Main Fault
ShF Shahtutak Fault


Kashaf Rud
Kashaf Rud
NMF
SMF
ShF
Sefid Kuh
Slice I
Slice I
Slice II
Slice II
Slice III
M2
M3
M2 + M3
K-e-N
K-e-F
K-e-P
K-e-M3?
Aghdarband
AGHD. ANTICLINE
AGHDARBAND SYNCLINE
Unit I
Unit I
Unit II
Units III + IV
Unit V
Unit V
0
1
2
3
4
5 km

Formation is outcropping all along this Slice, but the overlying Shale Member and the Miankuhi Formation are missing. The Nazarkardeh Formation containing the "Fossil Horizon 1" (Early Anisian) is well represented (fossil localities 25, 26 of the geological map, Pl. 1 in A. RUTTNER, this vol.). Red conglomerate of the Qara Gheitan Formation (Early Scythian) – substratum of the Triassic Aghdarband Group – appears only tectonically in contact with the Sina Formation NE of the Aghdarband village.

The central Slice (Slice II) consists of a broad SE plunging syncline, faulted towards NW against the Sandstone Member of the Sina Formation of Slice I. *Slice II shows the most complete Triassic lithological* sequence which is resting with a slight angular unconformity on the Early Scythian red conglomerate (Qarâ Gheitan Formation). The Sefid Kuh Formation (massive limestone) is well developed and seems to be complete in the W part (Sefid Kuh area, see BAUD et al., this vol.). But the Sandstone Member of the Sina Formation seems here partly to be uncomplete (tectonically reduced?) in comparison with its development in Slice I and Slice III. The Shale Member of the Sina Formation is well developed and contains a complete sequence of marine shales with tuffaceous epiclastic intercalations. The core of the syncline consists of the shale, siltstone and sandstone of the Miankuhi Formation, with the coal seam at its base. In the E part of the syncline, this last formation predominates, the northern limb being cut by a vertical (strike slip?) fault, and the southern limb being overthrust by the tectonic Slice III.

This southern Slice displays the shape of an overturned anticline, overthrusting Slice II and being overthrust by the southern Frame. Resting tectonically on the Early Scythian red conglomerate, the Sefid Kuh Formation is reduced in the W part and is thickening eastward. There appears a carbonate conglomerate layer on top of the Nazarkardeh Formation ("Fossil Horizon 1"). The Nazarkardeh Formation is well developed by tectonically disturbed at the W end of the Slice (see geological map, Pl. 1 in A. RUTTNER, this vol.). The Shale Member is still uncomplete and the whole Miankuhi Formation is absent (eroded?).

As described by RUTTNER (1984 and this vol.), the *southern (?)Paleozoic Frame is thrust northward in the* main Triassic outcrop.

3. The Sina Cross Section

The Sina coal mine is situated about 3 km E of the Aghdarband village. The cross section begins at the foot of a steep wall of "marble" (early Carboniferous) of the northern Frame, 300 m NE of the mine (stratigraphic section No. 9 on the geological map, Pl. 1 in A. RUTTNER, this vol.). From the north to the south, the section crosses first the Sina Formation of the northern Slice and the Miankuhi Formation of Slice II. The main part of the section is crossing the southern limb of the Kal-e-Anabeh anticline of slice III. The Sina cross section is illustrated in Fig. 2 and we are referring to the stratigraphic sections 9 to 3 of the geological map (Pl. 1 in A. RUTTNER, this vol.).

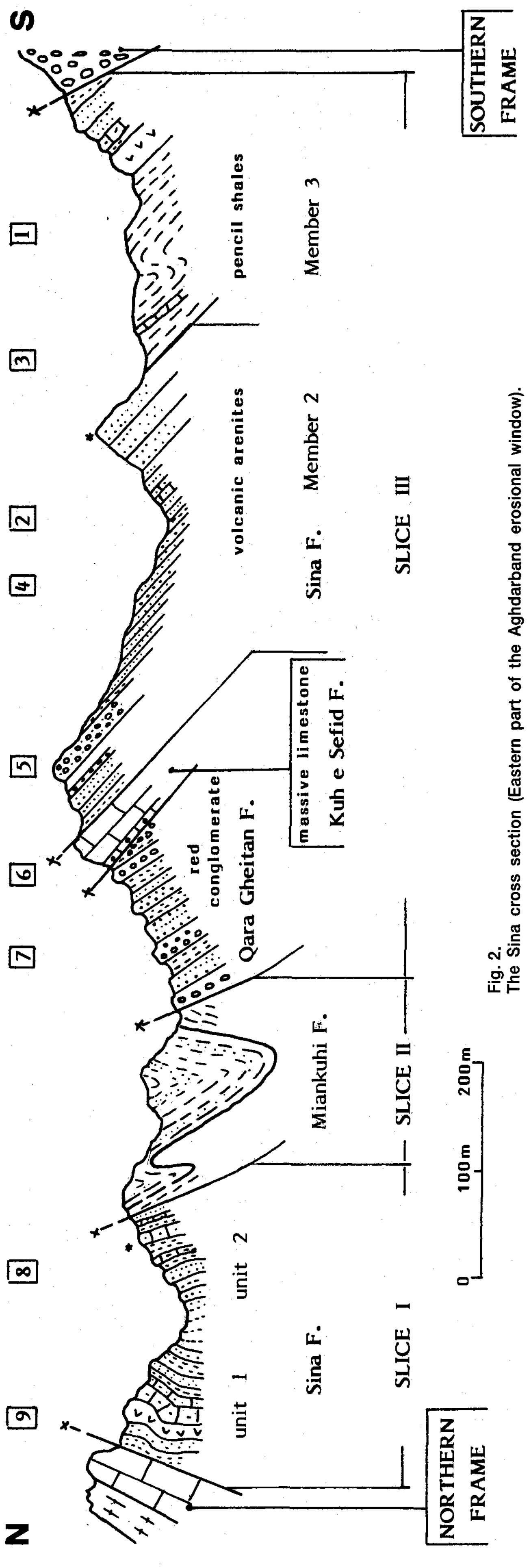


Fig. 2.
The Sina cross section (Eastern part of the Aghdarband erosional window).

3.1. Description of the Northern Part of the Section

(Fig. 3)

Part of the Sina Formation (Anisian–Ladinian) is exposed vertically and consists from the N to the S of an older red coloured volcano-sedimentary unit (unit 1) and a younger green coloured sedimentary unit (unit 2). This corresponds to stratigraphic sections Nos. 9 and 8, Pl. 1 in A. RUTTNER, this vol.).

The unit 1 (Fig. 3) is composed of three lithological sequences a, b, c. The lower one (a) is poorly exposed and consists mainly of medium bedded volcanic arenite with tuffaceous lithic and crystal components, andesitic in composition. The lithological sequence b, 30 m thick, is made of nodular marlstone interbedded with tuffaceous skeletal lime wackestone and packstone and volcanic arenite mixed components.

The upper part of the unit 1 (sequence c) consists of a thickening upward volcanic arenite cycle, calcareous in the top. The primary volcanic material, ashes, crystal tuff, lithic tuff, lapilli, have been transported in the deep marine environment by density current, mainly grain flow and debris flow, processes. The petrographical composition of the juvenile volcaniclastics is of 2 different types:

- Crystal fragments in a fine, vitrous hyalopilitic matrix of altered distal ashes.
- Lithic (lapillis) and fresh crystals (plagioclase and K feldspar) arenite in carbonate matrix.

The general composition of the volcanics is andesitic and the time of epiclastic processes seems to be rather short between the pyroclastic fragmentation and the final deposition.

The green color of the younger (Ladinian) unit 2 is due to the presence of chlorite (celadonite) in the matrix of the volcaniclastic beds. This unit (Fig. 3) is subdivided in 2 parts. The lower part (d) consists of green shales interbedded with volcanic arenite and rudite (microconglomerate). Petrographically, the volcanic arenites are not homogenous and the following types have been observed:

- Crystals of sanidine and plagioclase microliths in a pseudo-cherty matrix (devitrified glass).
- Lithic (rhyolitic, trachitic and cherty fragments) and crystal arenite in a chloritized, hyalopilitic matrix.
- From bad to well sorted lithic (granophyr and trachitic lava flows fragments) volcanic-arenite.
- Volcanic arkose and subarkose.
- Microconglomerate with trachytic pebbles.

The upper part of the unit 2 ((e) consists of pelagic, tuffaceous limestone interbedded with calcschists, greywacke and subordinate volcanic arenites. The skeletal fragments are "filaments" (thin shelled pelagic bivalves) and subordinate crinoidal stems and *Daonella* broken shells. The arenites are composed of crystals (sanidine and calcitized plagioclases) in a chloritized matrix containing also laumontite (zeolite group). The rare microconglomeratic epiclasts are trachytic to andesitic in composition.

These units correspond to the lower part of the Sina Formation. The same coloured lithological succession had been observed by Dr. RUTTNER at the base of the Sina Formation W of the Sefid Kuh area.

The Miankuhi Formation is partially exposed in the vicinity of the coal mine (N of stratigraphic section no. 7, Pl. 1 in A. RUTTNER, this vol.), where it is bounded by tectonic contacts; it belongs to the central tectonic Slice II constituing the complex core of the main Aghdarband syncline (not studied in detail).

3.2. Description of the Southern Part of the Section

(Slice III; Figs. 2, 4, 5)

The two lower Formations of the Aghdarband Group are represented in the southern limb of the Kal-e-Anabeh anticline (southern tectonic Slice III). The first lithological unit consists of the red conglomerate and shale of the Qara Gheitan Formation that is thrust on Slice II along a S dipping plane. This formation is overlain by the structurally reduced Sefid Kuh Formation. Above, with a tectonic contact, lies the Sandstone Member of the Sina Formation. The Shale Member follows stratigraphically without disturbances, but its upper part is cut by the S dipping thrust of the southern frame (Fig 2).

3.2.1. Red Conglomerate and Shale – Part of the Qara Gheitan Formation (Early Scythian)

This unit (No. 23 of the geological map, Pl. 1 in A. RUTTNER, this vol.) is the oldest one involved in the main tectonic Slices of the Aghdarband Group. About 100 m thick in this cross section (stratigraphic section No. 7 on the geological map) this unit consists of a regular succession of thick bedded conglomerate, medium bedded red sandstone and thin bedded red shale (Fig. 4). The well rounded, up to 0,1 m pebbles are mainly of quartzo-feldspathic composition and consist of granite, granophyre, rhyolite, gneiss and chert. The sandstones are predominantly greywacke and litharenite. Part of the quartz grains are strained. The K felspar (perthite or microcline) is more abundant than plagioclase. There are also biotite and muscovite from metamorphic rocks, magmatic zircon and lithic fragments of granopyhre, rhyolite phyllitic rocks and chert. The subordinate volcaniclastites are essentially aciditic in composition. This red conglomerate unit thus appears to have been laid down by large braided streams draining mixed basement (Hercynian?) metamorphic rocks and aciditic volcanites. The components of this unit are showing a regional epizonal metamorphism that is distinct from the overlying slighter metamorphosed or unmetamorphosed Triassic formations.

3.2.2. Massive Limestone – Part of the Sefid Kuh Formation (Spathian to Early Anisian)

(Stratigraphic section No. 6 on the geological map, Pl. 1 in A. RUTTNER, this vol.)

In this cross section, the structurally reduced Sefid Kuh limestone Formation is overlying the red conglomerate unit with a tectonic discordance of 15°. The variation in thickness is wide and changes from 5–10 m in the western part of the Slice to more than 100 m in the eastern part. A few samples have been taken from the stratigraphic section No. 6 and a sedimentological description will be given in the complete Sefid Kuh section (BAUD et al., this vol.).

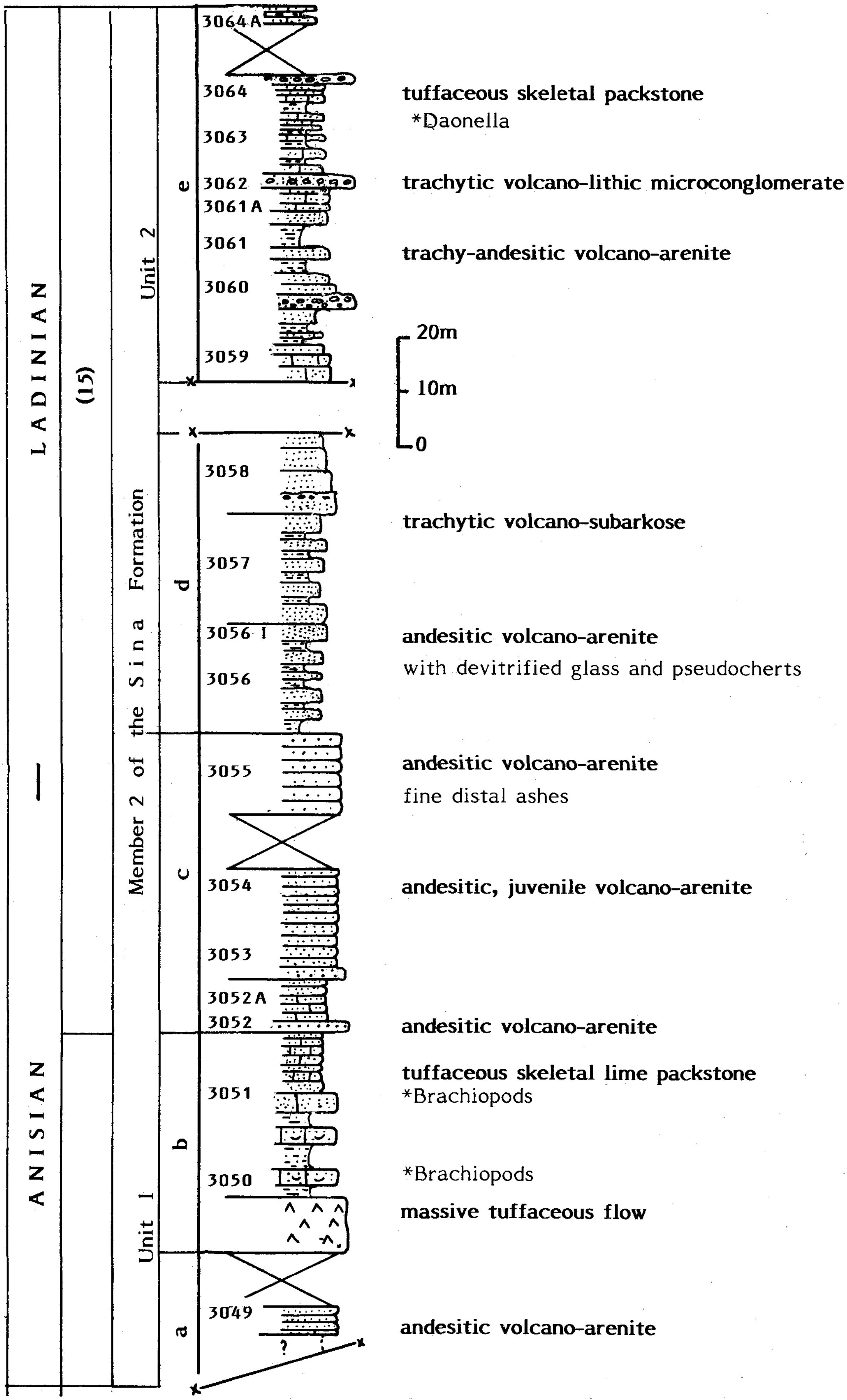


Fig. 3.
Part of the Sina Formation in the northern part of the Sina cross section (Tectonic Slice I).
Member 2 = Sandstone Member of the Sina Formation.

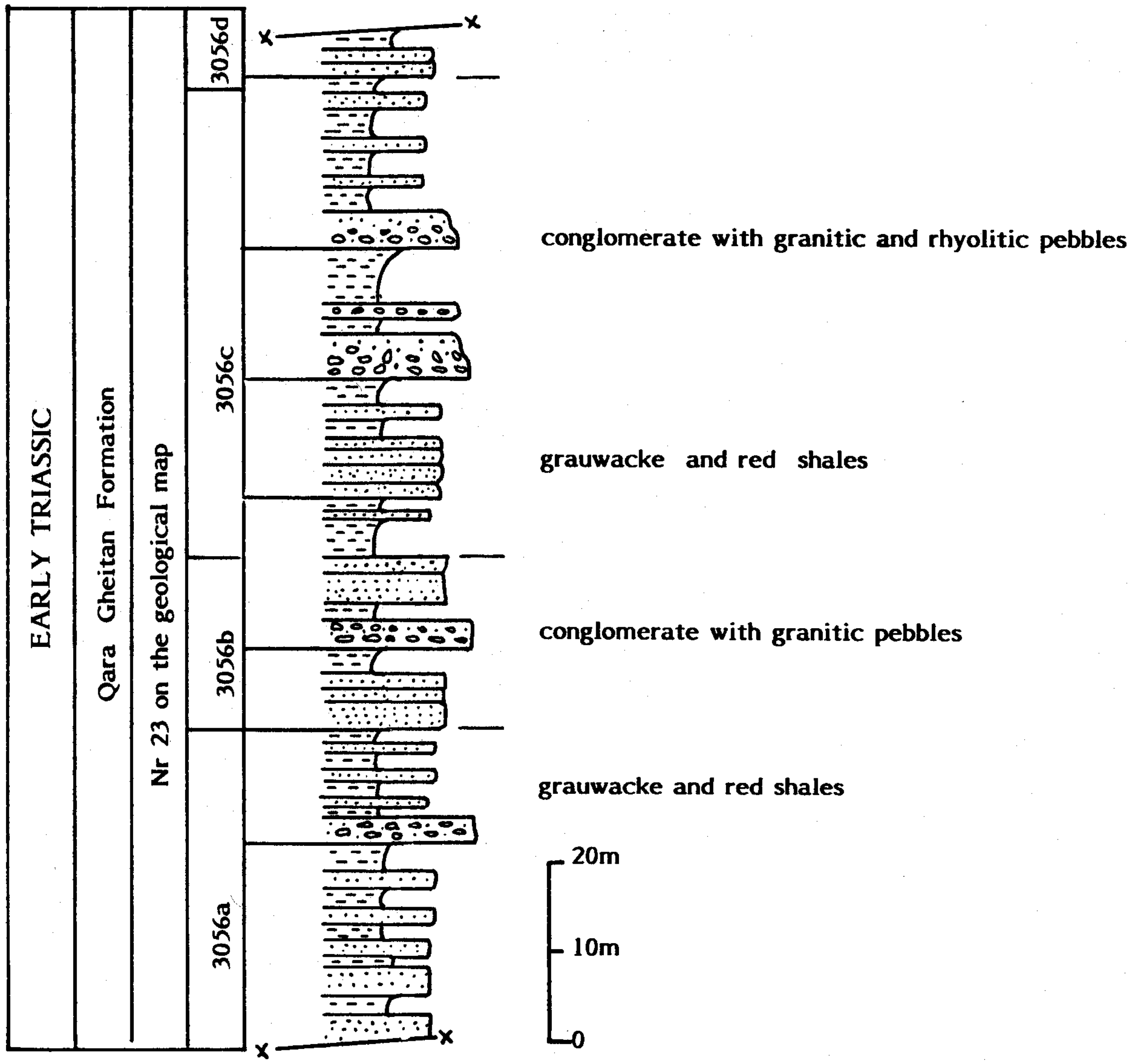


Fig. 4.
Part of the Qara Gheitan Formation in the southern part of the Sina cross section (Tectonic Slice III).

The main petrographical composition of these very shallow water limestones consists of high energy ooid-oncoid grainstones to pelletal packstones. Skeletal fragments are predominantly shells of mollusks (gastropods, bivalves). At the top of the limestone, paleokarstic features indicate emersion.

3.2.3. The Green Volcanic Sandstone and Conglomerate Unit (Sandstone Member of the Sina Formation, Middle Triassic)

A clear cartographic discordance (see geological map, Pl. 1 in A. RUTTNER, this vol.) separates tectonically this unit from the underlying massive limestone. The general section (Fig. 5) is reconstructed from the partial stratigraphic sections 5, 4, 3 and 2 (Pl. 1 in A. RUTTNER, this vol.) and is subdivided in 5 subunits, from A to E.

The subunit A (stratigraphic section 5) is correlated with the base of the Sandstone Member the Sina Formation (late Anisian?) and consists of fine grained calcareous greywackes interbedded with green to red calcareous shales and conglomeratic sandstone. The main coarse grained sandstones are petrographically calcareous volcanic litharenite and rudite. Andesitic to trachytic volcanic detritus is mixed with quartzo-feldspathic metamorphic fragments. Strained quartz is abundant, K felspar, plagioclase and muscovite are subordinate. This offshore deep ramp resembles deposits derived from both andesitic to trachytic volcanism and uplifted metamorphic basement.

The subunit B is correlated with the key bed No. 17 of geological map (Pl. 1 in A. RUTTNER, this vol.). This key bed (Anabeh conglomerate) is only present in structural Slice III).

This subunit consists of 2 coarse conglomeratic deposits, respectively 2 m and 8 m thick, separated by 5 m of coarse grained arenite. The conglomerates are tabular and grain supported with well rounded pebbles up to 0,1 m in diameter in a matrix of well sorted litharenite with felsic metamorphic fragments, chert, granophyre, abundant quartz and rare calcitized feldspars (microcline). The pebbles include very abundant bioclastic limestones and subordinate acid volcanic

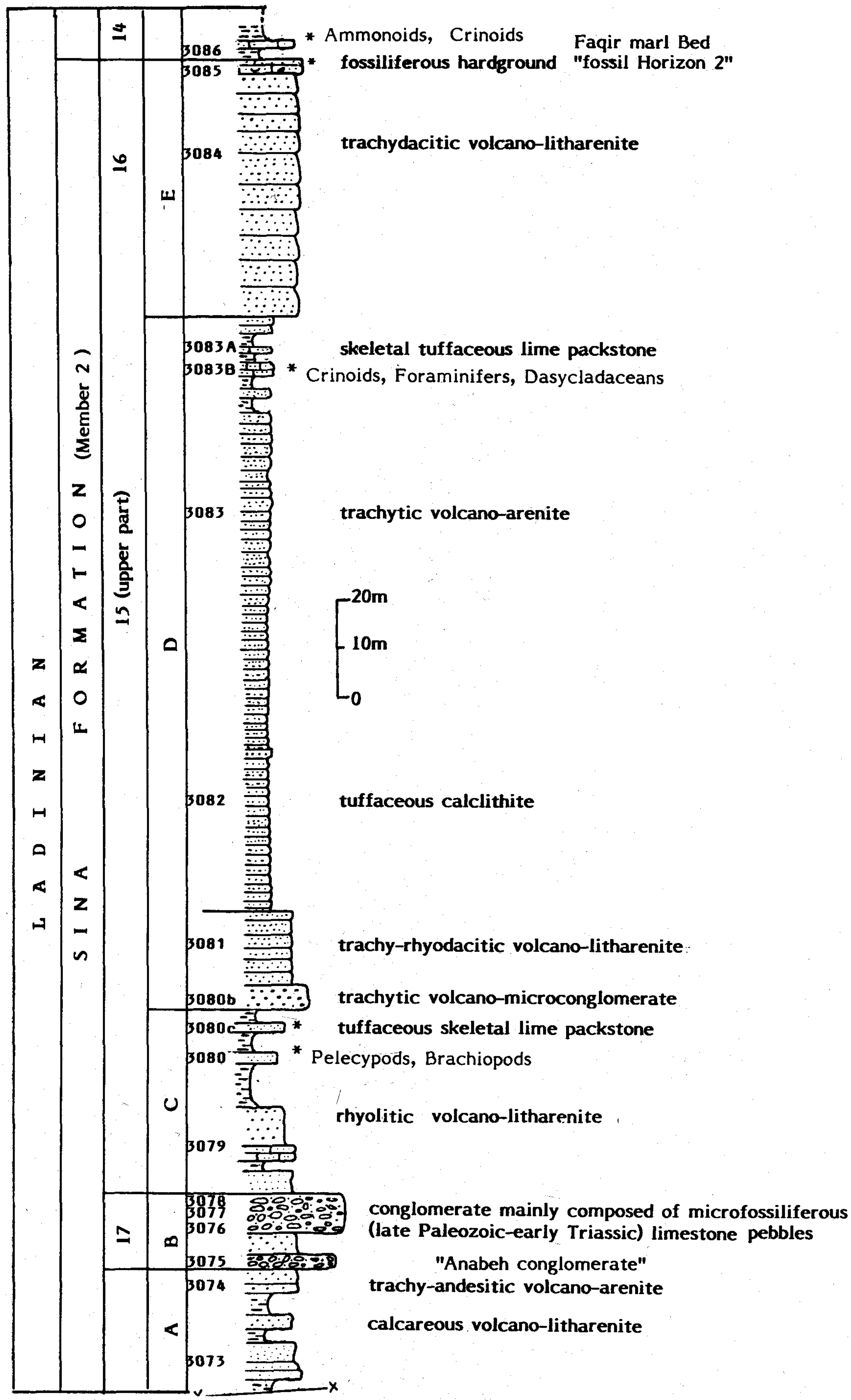


Fig. 5.
Sandstone Member of the Sina Formation in the southern part of the Sina cross section.

rocks and white qurartzarenite. Samples of the main limestone types have been analysed and consist of:

- Middle Carboniferous skeletal packstone with *Endothyra* sp., bereselidean and dasycladacean Algae.
- Late Permian (Dzhulfian?) skeletal wackestone-packstone with typical Elburz type microfauna that is similar to upper Nesen innershelf microfacies.
- Latest Permian silicified foraminiferal packstone with *Colaniella parva, Codonofusiella nana, Hemigordius* cf. *reicheli, Paleofusulina* sp., *Nodosaria* sp., *Kamurana* sp., *Langella* sp., *Pachyphloia* sp. and *Pseudovermiporella niponica*. This late Dzhulfian to Changhsingian microfaunal assemblage and microfacies are not known in the Elburz (ALTINER et al., 1979), nor in central Iran or in the adjacent S Turan plate. This is posing the problem of the disappearance of one complete paleogeographic domain as known in Eastern Tethys with a shallow water carbonate platform of latest Permian age. But, after JENNY & BAUD (1989) *Colaniella* faunas are still present in the late Permian carbonate platform, central Afghanistan, SW of Kabul.
- Early Triassic skeletal wackestone and oolitic-skeletal grainstone with *Meandrospira pusilla, Earlandia* sp., *Aghatammina* sp. and small Glomospires. This Elika type microfauna and microfacies as well is also the same as in the underlying massive limestone. These conglomerates are resedimented deep water deposits. The roundness of the pebbles and their composition suggest a beach or gravel bar origin adjacent to an uplifted crystalline basement with its late Paleozoic – early Triassic carbonate cover.

The subunit C (stratigraphic section 5, upper part) is overlying the Anabeh conglomerate and is about 40 m thick. It consists of fine grained volcanic arenite interbedded with red calcareous shale and tuffaceous, sandy skeletal limestone. The composition of the lithic grains is predominantly made up of pyroclasts with trachytic and pilotaxic textures and subordinate devitrified volcanic glass. Rare metamorphic felsic detritus is mixed with the volcaniclastites, and the skeletal fragments are mainly ornate shells of the pelagic bivalve *Daonella* sp.

The subunit D (stratigraphic sections 4 and 3) is about 160 m thick and consists of fine grained calcareous sandstone, tuffaceous calclithite, marly limestone and lime skeletal packstone. The lower 40 m part of the subunit contains graded microconglomerate interbedded with coarse grained volcanic litharenite. The fresh volcanic and well rounded detritus consists mainly of trachitic and rhyodacitic grains in a chloritized matrix with sanidine phenocrystals.

The calcareous composition of the following 100 m resedimented deposits is due to the complete late diagenetic calcitisation of the volcanic grains and the matrix. But the upper 20 meters of this subunit are clearly composed of sedimentary carbonate and consist of tuffaceous crinoidal lime packstone interbedded with calcareous shale.

Graded bedding, thinly laminated textures and sole marks indicate distal turbiditic deposits.

The subunit E forming the top of the Sandstone Member is correlated with the key bed No. 16 of the geological map (Pl. 1 in A. RUTTNER, this vol.). This cliff forming subunit, about 50 m thick, consists of thick bedded dark green volcanic arenite.

Well sorted volcanic litharenite with fragments of intermediate to aciditic compositon (trachytic – dacitic) in a chloritized matrix, mixed crystal and lithic arenite in carbonaceous matrix and tuffaceous crinoidal packstone are the main recorded petrographical types.

3.2.4. The Pencil Shale Unit – Part of the Shale Member of the Sina Formation (Late Ladinian to early Carnian)

This shaly unit has suffered an intense isoclinal folding and a pencil like superficial alteration. Its thickness in this cross section (Nos. 3 or 1, Pl. 1 in A. RUTTNER, this vol.), is estimated to be abut 100 m. This unit corresponds to the upper part of the Sina Formation (Shale Member). At the base, as noted by RUTTNER (this vol.), the Faqir Marl Bed ("Fossil Horizon 2") forms a conspicuous bed of marly skeletal tuffaceous sandstone corresponding to the key bed No. 14 of the geological map and is caped by a hardground with enrichment in skeletal elements as *Traumatocrinus*, brachiopods and ammonoids. The age is late Ladinian (KRYSTYN & TATZREITER, this vol.). Lithologically, this unit consits of thinly bedded calcareous shale with occasional plant remains and crinoidal stems, and of marly limestone interbedded with volcanic arenite and rudite, and tuffaceous skeletal lime wackestone to packstone with thin ornate shells of a *Halobia*-like bivalve. The tuffaceous limestone contains angular strained and unstrained quartz grains, K-feldspars, trachytic and chert fragments. The thin bedded calcareous shale and marl with pelagic bivalves, sponge spicules, and isolated crinoid stems suggest a distal, deep ramp environment.

In tectonic contact with the overlying conglomerate of the Southern Frame, the top of the section consists of thick bedded tuffaceous limestone and calcareous subgreywacke and coarse grained volcanic litharenite. This arenite contains angular unstrained quartz, K-feldspars, rare plagioclase, trachytic and orthoquartzite fragments, and muscovite in a carbonate matrix. Here also, we note mixed source rocks, derived from an active volcanic arc and from a metamorphic basement.

4. The Aghdarband Group

A detailed description is given in RUTTNER (this vol.). In the following pages we complete our investigations on the petrography of the volcanic arenite with the complementary additional samples provided by Dr. RUTTNER. Fig. 6 gives the correlations between the partial stratigraphic sections of the Sina coal mine area and the general Triassic stratigraphic section of RUTTNER (1984 and this vol.).

4.1. The Sefid Kuh Limestone Formation (Spathian)

This Formation (Member 1 of RUTTNER [1984]) consists of 200–250 m thick shallow water limestone in the Sefid Kuh area (BAUD et al., this vol.). The basal part of this Formation has been studied there by Dr. RUTTNER but the contact with the underlying Qara Gheitan conglomerate was partly hidden. At the base the massive limestone appears a black coarse grained to microconglomeratic volcanic sandstone of about 15 m thick. Petrographically, the sample 76/93/10 collected at the top of the volcanic sandstone consits of well sorted grains of volcanic rocks with trachytic textures, pumiceous vitric fragments and crystals of plagioclase (albite) and subordinate quartz in a celadonite matrix. The composition is andesitic.

Apparently conformably follows the basal part of the limestone that consists of high angle cross bedded calcarenite interbedded with tuffaceous limestone and calcareous volcanic microbreccia. Higher up, some angular unstrained quartz grains are present in the limestone facies.

4.2. The Nazarkardeh and the Sina Formations (Early Anisian to Early Carnian)

The lower part of the Sina Formation was called Tuff Member by RUTTNER (1984). But after re-examination of all samples and thin sections with Prof. RAY CAS (we thank him here), we arrive to the conclusion that they are not primary volcanic deposits and that all of the volcanic detritus have been reworked by gravity flow processes. For that reason, we cannot use the term "Tuff" which is only applicable to primary pyroclastic rocks (SCHMID, 1981).

The lower part of the Sina Formation is mainly composed of volcanic sandstone and subordinate limestone with conlgomeratic layers. The basal part consists locally of a thick conglomeratic body of well rounded pebbles, being the result of reworking the underlying limestone. This conglomerate overlies the "transition beds" (No. 19 on the geological map., Pl. 1 in A. RUTTNER, this vol.), representing now the newly established Nazarkardeh Formation (see A. RUTTNER, this vol., chapter 3.2.2.). The Nazarkardeh Formation contains the "Fossil Horizon 1" of early Anisian age (Osmani- and Ismidicus-zone [KRYSTYN & TATZREITER, this vol.]) and consists of pelagic skeletal packstone and resedimented limestone with volcaniclastic intercalations. A volcanic arenite (sample 75/37) interbedded in the pelagic limestone is composed of angular crystals of quartz and K feldspars, lithic fragments of trachyte, of low viscosity flows and of devitrified glass in a calcareous matrix.

In the overlying Sandstoner Member of the Sina Formation are thick bedded volcanic sandstones alternating with bioclastic calcareous shales. The sample 76/74 is a well sorted and coarse grained volcanic arenite. We note a large proportion of crystals with albitized K-feldspars and quartz, subordinate lithic fragments with trachitic and porphyric textures and devitrified glass. Matrix and elements are partially replaced by celadonite and also by calcite. Zeolites are present, indicating low grade anchimetamorphism. Near the top of the Sandstone Member, the sample 75/22b consists of a pelagic skeletal tuffaceous lime wackestone with ornate shell fragments belonging to *Daonella* sp. Volcanic quartz and devitrified glass replaced by calcite are abundant, K-feldspars and sericite are subordinate. The increase of volcanic quartz is interpreted as a change in the penecontemporaneous volcanism which became more aciditic (dacitic – rhyolitic). The same trend is also observed in the Sina section. An other sample (75/16) of the same horizon consists of pelagic tuffaceous skeletal lime packstone and is of mixed bioclastic and volcaniclastic origin. The last studied sample of the Sandstone Member (76/86) is a tuffaceous sublitharenitic limestone. Petrographically, crystals are quartz and calcitized feldspars. Lithic fragments consit of flow banded highly viscous magmas of both dacitic and trachytic compositon. This indicates here a mixture of fresh volcanic sources.

The Shale Member corresponds to the marine shale member of RUTTNER (1984). Five samples from the RUTTNER collection coming from the western part of the central tectonic Slice II have been examinated.

Near the base of this Member, the sample 76/65 is a well sorted tuffaceous subarenite. It consists of rounded quartz grains, K-feldspars, albite, muscovite, biotite, rare tourmaline and calcite. Lithic fragments are quartzo-felspathic and quartzo-pyhllitic rocks and volcanic glass. Comparing with the petrography of the underlying samples, we note an increase of metamorphic and plutonic grains coming from crystalline basement sources.

In the upper part of the Shale Member, the next two samples (75/15a–15b) are ankeritic recrystallized limestone with complete replacement of quartz and felspars grains by calcite.

Closer to the top, a thick bedded level, dark green in colour (No. 11 of the geological map, Pl. 1 in A. RUTTNER, this vol. is forming ridges and precipices (RUTTNER, 1984). The main facies consits of a coarse grained volcanic litharenite and volcanic microbreccia. The sample 75/67 is a calcareous volcanic microbreccia containing quartz, K felspars albite, and trachytic to rhyolitic fragments in a calcitic matrix. The spherical shape of this sample is an effect of calcareous concretionnement and the pillows described by RUTTNER in 1984 seem also to be carbonate concretions within the volcanic sandstone.

Conglomerates (level No. 13 on the geological map) overlie the massive sandstone. A well rounded pebble (sample 76/77) consists of ignimbrite, dacitic in compositon. Many of the phenocrystals, albite, K-eldpars and rare quartz are quite angular and occur in a devitrified matrix with secondary calcite. We have no indications of the general composition of the pebbles assemblages of these conglomerates; those occur only in the western part of the tectonic Slice II.

4.3. The Miankuhi Formation (Norian)

This youngest Formation of the Aghdarband Group consits of shales, siltstone and subordinate sandstone. At the base lies the "Coal Horizon" (No. 9 on the geological map) which is authochtonous and marks the first clear continental deposit of the Group. This horizon is overlain by coaly shales rich in plant remains (BOERSMA et al., this vol.) and by 3 to 5 m of thick bedded quartzarenite. Higher up are brown weathered shales interbedded with siltstone and rare sandstone, about 250 m thick, partly restricted marine in origin (A. RUTTNER, this vol.).

One of the two analysed samples coming of the hanging wall of the coal seam (75/19) is a fine grained, well sorted sublitharenite containing abundant plant remains and quartz, felspar, muscovite, biotite, secondary calcite and lithic fragments of phyllitic rocks. The other (75/94) is a volcanic litharenite with plant remains. This coarse grained sample with well rounded volcanic fragments contains devitrified glass, volcanic quartz and felspars, detrital phyllitic minerals (illite, muscovite) and opaque minerals. According to Dr. RUTTNER, this is the youngest volcaniclastic bed and no important volcanic detritus are found higher up in the Miankuhi Formation.

In the E part of the erosional window, the Aghdarband Group is unconformably covered by the "Rhaetian" continental shales as shown by the geological sketch map (Fig. 1).

5. Volcanosedimentary Evolution and Conclusions

From the petrographical analysis and after comparisons with adjacent areas, ancient and recent models, we can assume that the detritism of the Aghdarband Group originated from an active volcanic arc on a continental margin and we are interpreting the general depositional environment as a back-arc setting (see chapter 5.2.).

In Fig. 6 we indicate the main characters of each Formation of the Aghdarband Group and of the underlying red conglomerates.

5.1. Geological Events and Evolution of the Detritism

(Fig. 6)

During Triassic time, 9 geological events have been recorded, separated on the base of tectonic movements, or abrupt lithological or environmental changes. At the base of the Aghdarband Group, during early Spathian time, two events occur. The first is a major one with the superposition of non metamorphic marine andesitic volcaniclastics on continental red conglomerate. This red conglomerate of early Triassic age is considered as a synrift (back-arc) clastic deposit that drained mixed crystalline basement and epimetamorphic aciditic volcanic rocks. The epimetmorphism of the pebbles is variscan or older. The second event consists of the transgression of a shallow water carbonate platform (Sefid Kuh Formation) on the volcaniclastics and this event is dated as early Spathian (BAUD & BRANDNER & DONOFRIO, this vol.).

The next two events (3rd and 4th) occur during early Anisian. The third represents also a major break characterised by a tectonic phase consisting of strong vertical movements initiating the desintegration of the former carbonate platform. Part of it was uplifted and eroded, producing a thick limestone monogenic conglomerate. Another part of the platform sunk rapidly into water depth where turbidity currents became an important process of sediment transport. Dated by the "Fossil Horizon 1" as Bithynian (early Anisian), this 4th event corresponds to the replacement of the carbonate sedimentation by volcaniclastic supply probably in response to the effusion of juvenile andesitic volcanoes on the volcanic arc. During the middle Triassic, this volcanism evolves to a more aciditic composition.

The 5th event is recorded in the middle part of the Sandstone Member of the Sina Formation (early Ladinian) and is characterised by deep marine deposition of mixed carbonate – crystalline conglomerate following the erosion of crystalline basement and its late Paleozoic sedimentary cover. This rapid erosion is interpreted as the result of a new tectonic phase of block uplifting in transcurrent regime.

The sudden change between the mainly coarse detritism of the Sandstone Member and the fine detritism and carbonaceous deposists of the Shale Member of the Sina Formation form the 6th event which is dated by the "Fossil Horizon 2" as late Ladinian (KRYSTYN & TATZREITER, this vol.). The evolution of the detritism is characterized by an increase of felsic non volcanic grains and the deep marine deposits (deep ramp) evolve to more distal turbidite and pelagic limestone.

The 7th event occurs in the upper part of the Sina Formation (earliest Carnian [DONOFRIO, this vol.]) and consits of a sudden increase of the volcanic and tectonic activites as shown by massive volcanic sandstone supplies.

The next event (8th) occurs after a time gap (late Carnian – early Norian?) and consists of the coal seam deposition followed by a shallow clastic marine transgression (Miankuhi Formation; second sedimentary sequence of the Aghdarband Group). The filling up and the closure of the marine back arc basin characterizes this event. The latest event (9th) we would speak about is latest Norian to Rhaetian and corresponds to the first orogenic phase of the Indosinian orogenesis (FROMAGET, 1937), or the Cimmerian orogenic collage (SENGÖR, 1984) that affect all the S Turan plate. Elsewhere, a main orogenic phase postdates the latest Triassic. In the Aghdarband erosional window we can observe a general trend of northward thrusting and folding along WNW axes, combined with a sinistral lateral strike slip fault (A. RUTTNER, this vol.). The entire Paleozoic to Triassic sedimentary pile is involved in this cover deformation. Some particularities of this orogene and of the collisional aspect will be shortly presented in the next chapter; it will be dealt with in more detail in another publication (BAUD & STAMPFLI, 1989).

5.2. Tentative Paleogeographic and Geodynamic Model

During the late Paleozoic, the area of the Kopet Dagh had been accreted to the Turan plate and partly metamorphosed in the green schist facies as did the Band-i-Turkestan, the N Hindu Kush and the N Pamir (BAZHENOV & BURTMANN, 1982).

During Permian time, parts of these accreted terranes were uplifted, eroded and mainly the southern areas covered by red continental deposits. The Paleotethys active margin migrated to the S and a new volcano-plutonic arc was emplaced S of the Hercynian collage, just to the N of the new Paleotethys subduction zone. Elements of this magmatic arc are preserved in the N Indu-Kush and in the N Pamir.

During Triassic time, an arcuate marine volcano-sedimentary belt is traceable from the S Caucasus through the Kopet Dagh to the N Pamir (STAMPFLI, 1978; KAHIN, 1979, 1984, STÖCKLIN, 1980). Part of this

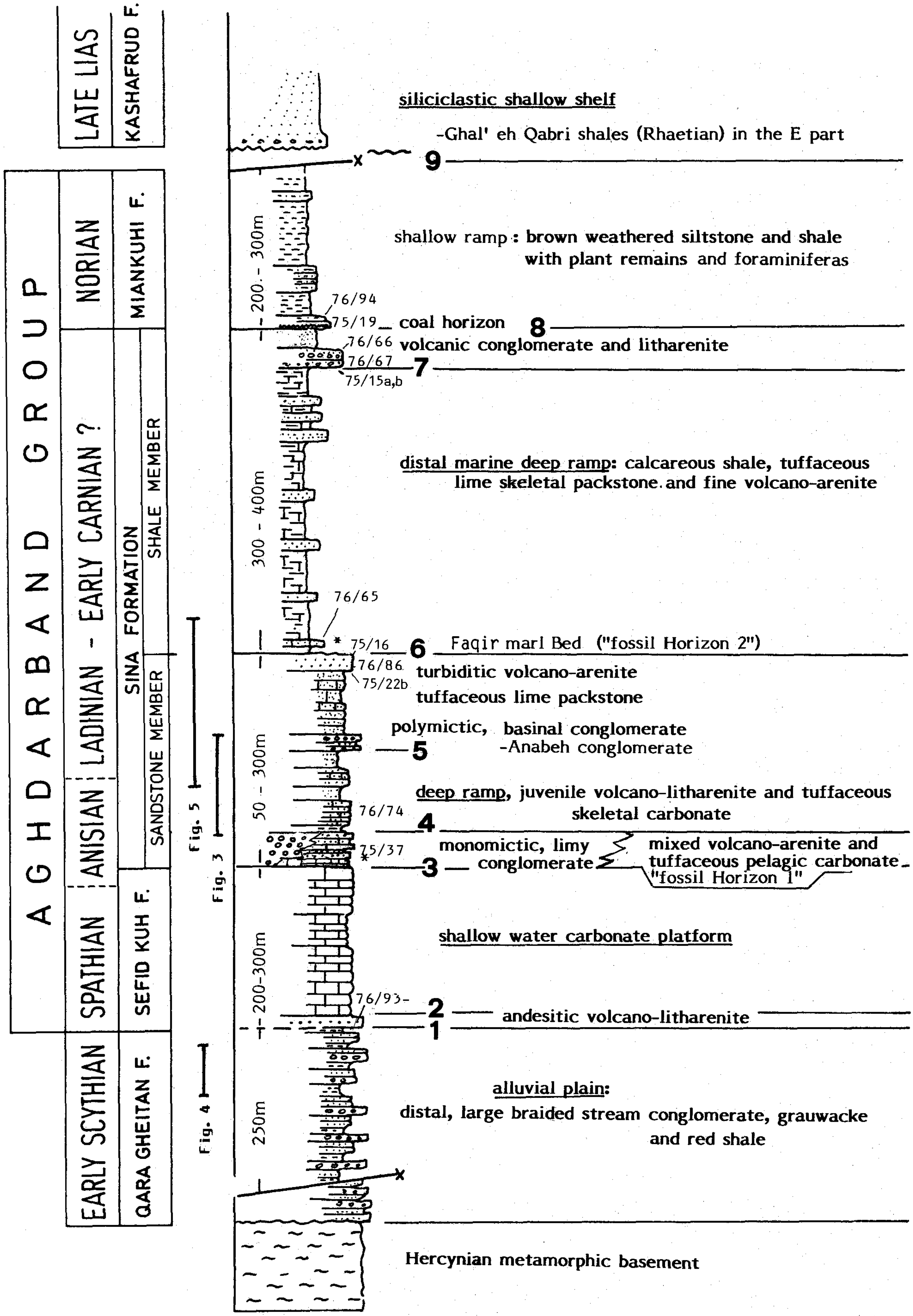


Fig. 6.
General Aghdarband lithological section with environmental interpretation, correlation of Figs. 3, 4 and 5, position of analysed samples. 1 to 9 are indicating the main geological events as described in chap. 5.1.
"Fossil Horizon 1" = Nazarkardeh Formation.

Triassic belt had been interpreted as an intracontinental rift zone (BASSOULLET et al., 1980; MONTENAT et al., 1980; BAZHENOV et al., 1982) or as a cratonic fissure (BOULIN et al., 1977, 1981). But the mode of emplacement in time and space, the geometry and the nature and composition of the marine clastic infilling this subsiding zone speak more in favour of a back arc basin setting than a simple intracontinental rift zone.

The first Triassic volcanic activity affected the late Scythian marine sediments, the main volcanic activity began in early Anisian (event 4) and ceased in latest Ladinian – early Carnian time. Very similar volcano-sedimentary evolution has been reported eastward by SLAVIN (1974) in Band-i-Turkestan, and by Boulin in N Indu-Kush.

The closure of the Paleotethys, the collision of the Cimmerian blocks against the Turan plate and subsequent uplift and deformations (Cimmerides orogenic collage of Sengor, or Indosinian orogenesis of FROMAGET (1937) or STÖCKLIN (1977, 1980) began here in latest Triassic time (A. RUTTNER, this vol.).

These deformations have affected the whole back arc area forming part of the Asian Cimmerides front of SENGÖR (1985). STAMPFLI (1978) and BRANDNER (1984) present the hypothesis of transform movements during the sedimentation and suggest oblique Cimmerian collages. In this sense, the hypothesis of a strike slip Indosinian orogenesis in Kopet-Dagh area can better explain the observed structures than the classical alpine type stright collision (BAUD & STAMPFLI, 1989).

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